ATMOSPHERIC PROPERTIES OF RU LUPI DERIVED FROM HIGH- AND LOW-RESOLUTION IUE SPECTRA

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ABSTRACT

High- and low-dispersion IUE spectra of the pre-main sequence star, RU Lupi, have been obtained using both the SWP and LWR cameras. Strong P Cygni line profiles are seen in Mg II and Fe II emission lines, indicating that the lines are formed in the stellar wind of RU Lupi. An increase in transition region line widths is seen with increasing temperature, which cannot be due solely to opacity broadening, thus indicating that kinematic broadening mechanisms (e.g. flows and turbulence) are dominant. The transition region density is $\sim 3 \times 10^{10}$ cm^{-3} derived from the Si III λ1892/C III λ1909 line ratio. The status of our atmospheric modeling of RU Lupi is discussed.

INTRODUCTION

The T Tauri stars are pre-main sequence (PMS) objects which show many chromospheric phenomena in their most extreme form. IUE has allowed the study of a number (~30) of these stars at low dispersion but high dispersion spectra have proved difficult to obtain even for the Mg II resonance lines, which generally need several hours of exposure time. RU Lupi shows the strongest observed chromospheric and transition region (TR) emission lines of all PMS stars and we have therefore studied this star extensively at high and low dispersion with IUE.

RU Lupi is among the most extreme of the T Tauri stars in that emission from its expanding atmosphere dominates its photospheric radiation in both the UV and optical spectral regions. Lago (1982) has constructed an atmospheric model for RU Lupi based on its optical spectrum and Penston and Lago (1982) have discussed earlier IUE observations of this star.

IUE OBSERVATIONS

We have obtained spectra of RU Lupi during the period 1983 April 15-16. These spectra include both high dispersion (SWP 19736, 755 min; LWR 15755, 416 min; LWR 15746, 40 min) and low dispersion (SWP 19739, 120 min; LWR 15745, 25 min; LWR 15754, 8 min) exposures. These data have been combined with earlier spectra, particularly the high-dispersion image SWP 14980 (316 min), in order to investigate the UV spectral properties of RU Lupi.

The low-dispersion SWP spectrum of RU Lupi is shown in Fig. 1 and the observed line fluxes derived from this spectrum, $F_{\oplus}$, are given in Table 1. The flux, F_{corr}, corrected for interstellar absorption (A_V = 0.6 mag; Cohen and Kuhi 1979), using the mean interstellar extinction curve of Savage and Mathis (1979) is also given. Profiles of the stronger SWP emission lines are shown in Fig. 2. These profiles are obtained from the addition of images 19736 and 14980 weighted by the relative exposure times. It seems likely that the line fluxes in the later exposure were somewhat lower. Line widths (FWHM) were derived for several lines and are given in Table 1. Figure 3 shows the LWR spectral region containing the UV1 multiplet of Fe II.

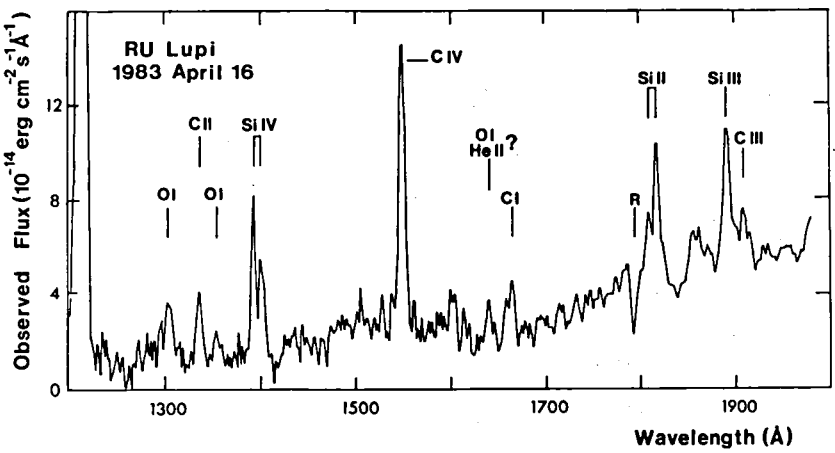

Fig. 1. The low dispersion spectrum (SWP 19739) of RU Lupi. The more prominent emission lines are identified. The line near 1660 Å, identified as C I, includes a significant flux from the O III intersystem lines at 1661 and 1666 Å. Reseaux are marked by 'R.'

Table 1: RU Lupi Emission Line Fluxes and Widths

Ion	λ (Å)	$F_{\oplus}$ (10^{-13} ergs cm^{-2} s^{-1})	F_{corr} (10^{-12} ergs cm^{-2} s^{-1})	Δλ (Å)
N V	1240	≤0.5	≤0.3	
S I	1296	0.9	0.5	
O I	1304	2.2	1.2	
C II	1335	2.0	1.0	
O I	1356	1.1	0.6	
Si IV+O IV	1397	6.3	3.0	0.95 (λ1394)
Si II	1529	≤6.1	≤0.4	
C IV	1549	9.5	4.2	1.05 (λ1548)
He II, O I	1640	1.2	0.5	
C I	1657	1.2	0.5	
O III	1663	1.9	0.8	
Si II	1814	5.8	2.4	0.76 (λ1808)
Aℓ III	1858	2.2	0.9	
Si III	1892	4.7	2.0	0.99
S I	1900	1.1	0.5	
C III	1909	1.4	0.6	
S I	1915	0.7	0.3	
C II	2325	7.5	3.8	
Aℓ II	2670	6.3	2.1	
Mg II	2800	≥69	22	

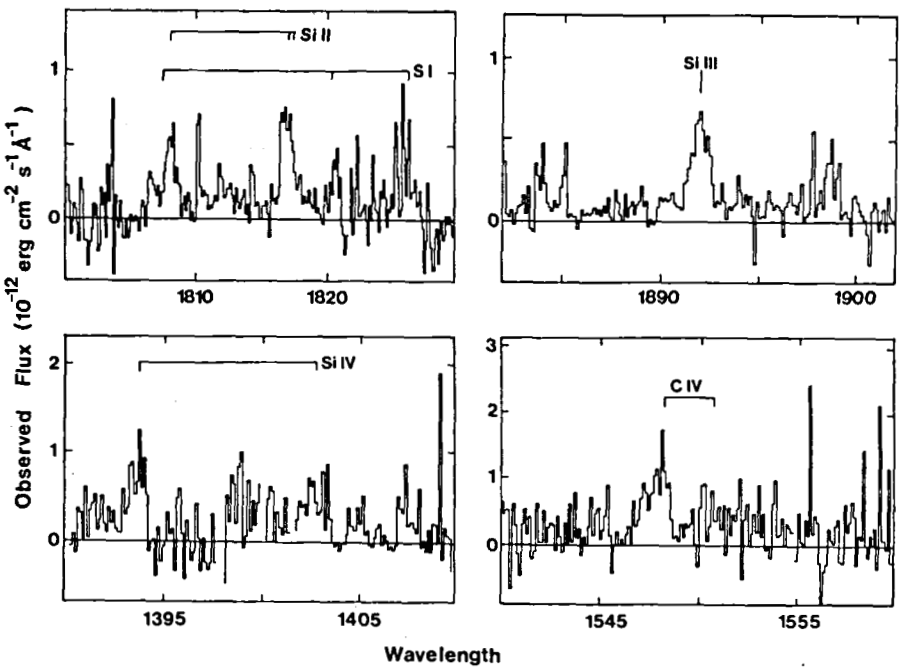

Fig. 2. High dispersion line profiles obtained from the summation of two SWP images of RU Lupi. Bright noise spots were removed from SWP 14980 by reprocessing the image with a median filter set with a suitable threshold. The expected positions of certain emission lines are indicated.

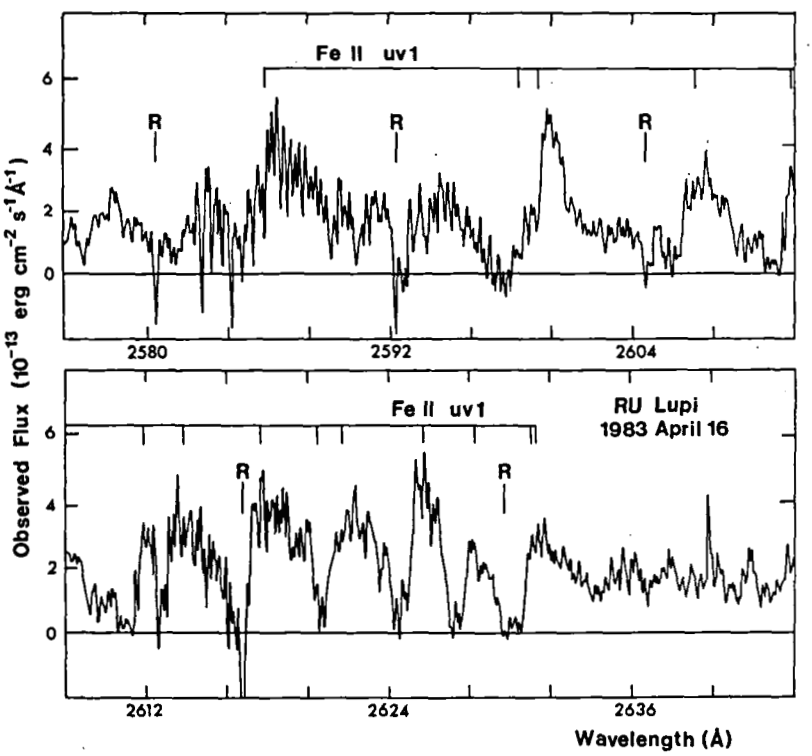

Fig. 3. High dispersion spectrum of the region containing the Fe II UV1 multiplet. The positions of the members of the UV1 multiplet are shown and clearly the lines show classical P Cygni profiles. The spectrum has been smoothed with a 3 point running mean. R denotes reseaux marks.

RESULTS PERTAINING TO THE ATMOSPHERIC PROPERTIES OF RU LUPI

The results derived from our preliminary analysis of these data are:

1. The Fe II UV1 and Mg II resonance lines show strong classical P Cygni line profiles formed in the stellar wind of RU Lupi. While such profiles are generally seen in the Mg II lines of T Tauri stars, strong P Cygni profiles in Fe II have not been seen before. These Fe II profiles are more extreme than the asymmetries seen in the lines of evolved cool giants and supergiants. We intend to model these profiles using co-moving frame radiative transfer techniques, which incorporate velocity fields, a chromospheric rise and PRD effects.

2. The observed line widths imply an increase in line broadening with temperature (i.e. the FWHM are ~125 km s^{-1} for Si II λ1808; ~155 km s^{-1} for Si III λ1892, and ~200 km s^{-1} for Si IV λ1394 and C IV λ1548). While some opacity broadening may be present in the resonance lines, this cannot be the case for the optically-thin Si III line. Kinematic effects, such as flows and turbulence, appear to be the dominant broadening mechanisms.

3. Assuming solar abundances, the Si III λ1892/C III λ1909 ratio of 3.3 indicates that the TR pressure at $\sim 6 \times 10^4$ K is $\sim 2 \times 10^{15}$ cm^{-3} K, equivalent to a local electron density of $\sim 3 \times 10^{10}$ cm^{-3}. The calibration of this line ratio used is that of Jordan (1983, private communication), which includes improved atomic data for Si III as compared to that of Doschek et al. (1978).

4. The emission measure distribution of chromospheric and TR plasma can be derived from the data in Table 1. We intend to calculate models of the temperature and density structure of RU Lupi using emission measure analysis (see, for instance, Brown, Ferraz and Jordan 1984). Since both the upper limit to the N V emission measure ($T_e \sim 2 \times 10^5$ K) is low and the Einstein X-ray upper limit (Gahm 1981) implies an even lower coronal ($T_e \sim 10^6$ K) emission measure, it seems that very little coronal plasma is present in the atmosphere of RU Lupi (Brown and Jordan 1983; Imhoff and Giampapa 1982).

Since emission from the stellar wind of RU Lupi dominates photospheric radiation in the UV and optical spectral regions, the combination of emission measure analysis, co-moving frame PRD calculations and previous optical studies should allow the consistent modeling of the atmosphere of RU Lupi.

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